A prospective study exploring the construct and predictive validity of the COM-B model for physical activity

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Abstract

This study examined the constructs of Capability, Opportunity, and Motivation from the COM-B model and their influence on moderate-to-vigorous physical activity (MVPA). Using a prospective survey design, 186 healthy adults completed measures representing the Theoretical Domains Framework mapped to the COM-B, and MVPA one week later. The main indicators for the COM constructs were 'habits' (Capability), 'subjective norms' (Opportunity), and 'exercise self-identity' (Motivation). Motivation (77%) and MVPA (50%) were strongly predicted, with Capability and Motivation as key drivers of behaviour. Motivation was a strong mediator for Capability on behaviour. Future research should consider this approach for other populations and behaviours.

Keywords: COM-B; physical activity; health behaviour; Theoretical Domains Framework.

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Less than two-thirds of adults in the United Kingdom (UK) perform the recommended level of physical activity on a regular basis (Sporting Lives, 2017), leaving them at greater risk of long-term health problems such as cardiovascular disease, stroke, type 2 diabetes, and cancer (Rhodes et al., 2017). Therefore, there is a need for effective, replicable, and scalable physical activity interventions. However, interventions to change health behaviours have often suffered from a poor description of their content and implementation (i.e. the how, what, and where; Hoffmann et al., 2014), the specific behaviour change techniques (BCTs) utilised (Michie et al., 2013), and the underlying theoretical basis (Michie et al., 2009). Without a

sound theoretical basis which both predicts physical activity levels and provides a rationale for the design of physical activity interventions, as well as criteria for its success, it is difficult to evaluate empirical evidence and replicate. A review of health eating and physical activity interventions found that only 56% reported using any theory at all, 24% measured pre-post changes in theoretical constructs, and just 5% targeted all theoretical constructs with specific intervention techniques (Prestwich et al., 2014).

Psychological models have been used to explain individual differences in physical activity. A common model used is the Theory of Planned Behaviour (TPB; Ajzen, 1991), which aims to understand behaviour via the antecedents of attitude, subjective norms, and perceived behavioural control and their influence on intention and behaviour. A systematic review (McEachen et al., 2011) confirms that the TPB predicts between 24-27% of variance in physical activity performance, but this can vary by type of sample (students - 30%, adults - 21%) and measurement (self-report - 26%, objectively measured - 12%). However, a further meta-analytic study did not provide strong evidence for the causal link between changes in intention and behaviour suggested by the TPB and other models (Webb and Sheeran, 2006). Of the five intervention studies included in this review all were able to produce a significant increase in intentions, but were ineffective in changing physical activity behaviour. Interventions based on the Transtheoretical Model (Prochaska and Di Clemente, 1982) are also not successful in changing physical activity (Bridle et al., 2005). One of the reasons for the lack of predictive validity of these models is that they omit important influences on physical activity such as self-regulation and affect (Rhodes and Dickau, 2012), as well as wider aspects such as physical capability and opportunity. As yet, the usefulness of these models to serve as a framework for designing physical activity interventions is limited.

In providing a more clearly defined systematic approach to designing behaviour change interventions, Michie et al. (2011) reviewed existing frameworks and found that none

combined comprehensiveness, coherence, and a clear link to a model of behaviour change. The previous frameworks were, therefore, synthesised into the Behaviour Change Wheel, which allows systematic development of behaviour change interventions (Michie et al., 2014). At the centre of the Behaviour Change Wheel is the COM-B model of behaviour. The COM-B specifies Capability (physical and psychological), Opportunity (social and physical), and Motivation (reflective and automatic) as the drivers of behaviour. The model also posits that both Capability and Opportunity influence Motivation making it the central mediator of the model. Capability and Opportunity, therefore, affect behaviour through an indirect as well as a direct path.

In summarising theories of behaviour that often contain overlapping constructs, 33 theories and 128 theoretical constructs were synthesised (Michie et al., 2005), leading to the Theoretical Domains Framework (TDF), consisting of 14 domains (Cane et al., 2012). The TDF covers the spectrum of behavioural determinants and can be directly mapped on to the COM-B (Cane et al., 2012). These include constructs aligned to those mentioned previously in earlier theories such as the TPB (i.e. beliefs about capabilities = perceived behavioural control/self-efficacy). Each domain can be further specified by a number of core components. For instance, the behavioural regulation domain contains self-monitoring, breaking habit, and action planning components (Cane et al., 2012). However, the relevance of these TDF components depends on the target behaviour as well as on its target population. The comprehensive coverage of the TDF allows researchers to analyse the most important domains specific to their populations and behaviours of interest. This allows a crucial step forward in predicting, and ultimately changing, physical activity by providing a much wider range of determinants than previous models have afforded.

This study explores the usefulness of the TDF for empirically identifying measures that are appropriate to represent the key drivers, Capability, Opportunity, and Motivation which, according to the COM-B, can be expected to influence levels of physical activity (Michie et al., 2011). Our research is a first step towards the development of a measurement model in the area of adult physical activity. The three constructs of the COM-B represent theoretical or latent variables which require an operationalization resulting in a measurement model. A measurement model displays the relationship between the selected measures for each construct and can be examined for its goodness of fit. Our study opted for a formative rather than a reflective measurement model (Perron and Gillespie, 2015), where the content of a construct is defined by its empirical indicators (i.e. the actual measures). Crucially, this implies that its content can change with different measures being selected. By contrast, in a reflective model the constructs are assumed to exist as latent variables and to influence the selected measures serving as empirical indicators (Bollen and Lennox, 1991; Bollen and Diamantopoulos, 2015).

There is currently no standardised measurement or wording format to capture the domains of the TDF or components of COM-B. Because the constructs of the COM-B depend on the population and behaviour in question, they cannot be assumed to represent unique entities that are quantifiable by a set of standard measures. Rather, their content can vary considerably between studies and so they have been conceptualized by domains from the TDF, each with its own range of potential components. The COM-B constructs are, therefore, more appropriately defined as an index, where each of the selected measures contributes to its formation according to its weight (Diamantopoulos and Winklhofer, 2001). Because a formative measurement model rests on the assumption that the selection of indicators for defining a construct is valid, it is important to evaluate whether their links (i.e. weights) with the corresponding construct are each statistically reliable and of notable size.

The recent combination of Partial Least Squares (PLS) with Structural Equation Modelling (SEM; Hair Jr et al., 2014; Henseler et al., 2016) provides an ideal statistical framework for such an exploration as it allows researchers not only to evaluate a proposed formative measurement model of the COM-B, but also the predictive validity of the constructs with respect to physical activity. Accordingly, we investigated the following hypotheses in a sample of healthy adult participants;

(1) The three constructs, Capability, Opportunity, and Motivation of the COM-B can be represented as latent variables each defined by selected measures representing domains from the TDF
(2) Each COM-B construct uniquely accounts for a portion of the variance in moderate-to-vigorous physical activity (MVPA) over a one-week period
(3) Capability and Opportunity will influence MVPA directly as well as indirectly with Motivation as a mediator

Method

Participants

This study used a prospective survey design using questionnaires relating to the TDF completed at baseline and the assessment of MVPA collected seven days later. Individuals were eligible for participation if they had no conditions preventing them performing regular physical activity, were over 18, and resided in the UK. Data were collected using opportunity sampling between November 2014 and April 2015. In total 214 participants completed an online survey, but 11 were excluded (one was under 18, 10 were not residents of the UK) and 17 did not respond to contact requests for the follow-up phone call. The final sample size was 186 and relevant demographic information is included in Supplementary Table 1. A

sensitivity analysis revealed that this sample size was large enough to detect a modest effect size correlation (r = .23) with a power of .90 and an alpha error of 5% (two-tailed).

Measures

Measures were selected based on published components mapped onto TDF domains listed within Table 2 of Cane et al. (2012). The 14 TDF domains are: Knowledge; Skills; Memory, attention and decision processes; Behavioural regulation; Social influences; Environmental context and resources; Social/Professional role & identity; Beliefs about capabilities; Optimism; Beliefs about consequences; Intentions; Goals; Reinforcement; Emotion. Measures were selected for components relevant for MVPA and where published questionnaires could be identified. There were some TDF components that were deemed unnecessary to measure. For example, under the knowledge domain the following three components are listed: Knowledge (including knowledge of condition /scientific rationale); Procedural knowledge; Knowledge of task environment. Procedural and environment knowledge would only be relevant for a particular form of exercise in a particular place (i.e. playing tennis in a public park), and not for generic MVPA. Therefore these components were not measured in this study. In contrast, within the behavioural regulation domain, self-monitoring, breaking habits, and action planning are all relevant for MVPA and therefore measures were identified for all three components within this domain.

Five measures were identified as defining the Capability construct, seven for Motivation and six for Opportunity (see Supplementary Table 1 for descriptive statistics). The following measures were used as formative indicators for Capability, Opportunity, and Motivation, with higher scores representing high levels in each domain (e.g. stronger intentions or a greater level of self-monitoring or knowledge.

Insert table 1 about here

Capability construct (5 measures)

Physical ability (skills) was measured with the 10-item physical functioning scale of the Medical Outcomes Short Form Survey (Ware and Sherbourne, 1992). The items were activities one might do during a typical day (e.g. climbing several flights of stairs). Participants were then asked about how much their health limits them in these activities and, if so, how much on a scale from 1 '*Yes, limited a lot*' to 3 '*No, not limited at all*'. This scale showed excellent reliability (a = .87).

Ability to self-monitor was measured by two items, which asked participants to rate how much they agreed with statements such as 'I constantly monitored myself whether I exercise frequently enough' on a scale from 1 '*Completely disagree*' to 4 '*Totally agree*', retrospectively over the past week (Sniehotta et al., 2005a). This scale showed good reliability (a = .82).

Ability to plan for action was measured by four items about when, where, how, and how often participants had made detailed plans regarding physical activity on a scale from 1 '*Completely disagree*' to 4 '*Totally agree*', retrospectively over the past week (Sniehotta et al., 2005b). This scale showed excellent reliability (a = .98).

Ability to control habit was measured with the Self-Report Habit Index (Verplanken and Orbell, 2003), containing 12 items exploring the past history and automaticity of their physical activity. The items were prefaced by 'Regular exercise is something…' Participants were then asked to rate the extent to which they agreed with each statement (e.g. 'I do without thinking') based on a 7 point scale from 1 '*Disagree strongly*' to 7 '*Agree strongly*'. This scale showed excellent reliability (a = .96).

As there was no validated measure, knowledge of physical activity was measured by asking participants three multiple choice questions, which map directly onto the three main parts of the national physical activity guidelines (NHS Choices). The questions referred to the recommended amount of moderate, vigorous, and muscle-strengthening activity, adults

should perform per week. For example, 'How much time should you spend doing moderate physical activity a week'? The answer options were '*50*', '*100', '150',* or '*200 minutes'*.

Opportunity construct (4 measures)

Barriers and facilitators in the local environment (within a 20 minute walk from residence) for physical activity were measured with the Neighbourhood Environment Scale (Echeverria et al., 2004) which consisted of 10 items. An example item was 'My neighbourhood offers many opportunities to be physically active', with responses on a scale from 1 '*Strongly disagree*' to 5 '*Strongly agree*'. This scale showed acceptable reliability (*a* = .72).

The availability and condition of local resources (within a 20 minute walk from residence) was also explored using the Presence of Recreational Facilities Index (Echeverria et al., 2004) consisting of six items. The availability of each type of facility (e.g. public park) was measured based on a yes or no answer. The condition of the facilities was then measured on a scale from 1 '*Poor*' to 4 '*Excellent*' if applicable.

Subjective norms were measured with three items (Francis et al., 2004). Each item referred to the amount of physical activity the individual would do over the next week that was influenced by their social environment and was rated on a 7-point scale from 1 '*Strongly disagree*' to 7 '*Strongly agree*'. One item was removed ('I feel under social pressure to take part in regular physical activity over the next week'), which improved the reliability (from *a* =.50 to *a* = .60).

Social support for physical activity was measured with 10 items from the Social Support for Exercise Behaviour Scale (Sallis et al., 1987). Five items assessed support for physical activity from friends, acquaintances or co-workers, and five items measured support from family (members of household). An example of 'exercised with me' asked participants to rate how often in the last week the people around them had done or said these things on a

scale from 1 '*None*' to 5 '*Very often*'. Both scales showed excellent reliability (*a* = .88 and *a* = .89 respectively).

Motivation construct (6 measures)

Self-efficacy was measured with the Physical Exercise Self-Efficacy Scale (Schwarzer and Renner, 2009), which consisted of five items exploring participants' ability to carry out their behavioural intentions in the face of challenges, such as 'even when I feel tense'. The items were measured on a scale from 1 '*Very uncertain*' to 4 '*Very certain*' and showed excellent reliability (*a* = .88).

Perceived behavioural control was measured with four items (Francis et al., 2004). Each item referred to the amount of physical activity the individual will do over the next week. Three items were rated on a 7-point scale from 1 '*Strongly disagree*' to 7 '*Strongly agree*', and included statements such as 'The decision to take part in regular physical activity over the next week is beyond my control'. One item asked participants to rate how difficult it was going to be to engage in physical activity over the next week on a scale from 1 '*Very difficult*' to 7 '*Very easy*'. This scale showed good reliability (*a* = .74).

Attitudes were measured with four items (Francis et al., 2004). Each item referred to beliefs in terms of how harmful, healthy, enjoyable, and boring physical activity was viewed on a set of 7-point scales anchored by negative and positive views (e.g. 1 '*Very unhealthy'* to 7 '*Very healthy'*). This scale showed acceptable reliability (*a* = .69).

Intentions were measured with three items (Francis et al., 2004). Each item referred to the amount of physical activity the individual intended to do over the next week with statements such as 'I expect to take part in regular physical activity over the next week'. Each item was rated on a 7-point scale from 1 '*Strongly disagree*' to 7 '*Strongly agree*' and showed excellent reliability (*a* = .91).

Exercise self-identity was assessed by the nine-item Exercise Self-Identity Scale (Anderson and Cychosz, 1994), which measured whether exercise is descriptive of an individual's self-concept. An example was, 'I consider myself an exerciser' measured on a scale ranging from 1 '*Strongly disagree*' to 7 '*Strongly agree*'. This scale showed excellent reliability (a = .96).

Positive and negative affect were measured with the International Positive and Negative Affect Schedule Short Form (Thompson, 2007), which consisted of 10 items that cover negative (e.g. afraid) and positive (e.g. inspired) affect. Participants were asked on a scale from 1 '*Never*' to 5 '*Always*' how often they had felt each item over the last week. The scales showed good (positive, a = .83) and acceptable (negative, a = .75) reliability respectively.

Dependent variable

Physical activity was measured with the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003). Four questions assessed the level of MVPA of each participant by asking the amount of time spent being active and on how many days for both moderate and vigorous intensities. The questionnaire was administered over the phone to reduce the tendency for participants to overestimate their self-reported activity on this measure (Lee et al., 2011). Engaging in more detailed probing through a phone call, allowed a more thorough exploration of each instance of activity. This improves the accuracy of reporting, often reducing the over-reporting of both the time spent and intensity of physical activity (Rzewnicki et al., 2003). In order to correct for outliers, reported moderate or vigorous physical activity which exceeded 180 minutes in any day was truncated to be equal to 180 minutes (nine participants). A Metabolic Equivalent of Task (MET) score was then calculated for each activity type by weighting its energy requirements, with 4 METs for moderate-intensity activity and 8 METs for vigorous-intensity activity. A total MVPA MET score was

then calculated from the sum of moderate and vigorous-intensity MET-minutes/week score (International Physical Activity Questionnaire, 2005).

Procedure

This research was approved by the University of Hertfordshire Health and Human Science Ethics Committee with Delegated Authority (protocol number: aLMS/SF/UH/00079). A survey link was posted on social media sites (Facebook, Twitter, LinkedIn), relevant online forums (postgraduate, research), and distributed by email and online by colleagues and public health contacts. Participants gave their consent electronically and were then taken to a page asking for a preferred contact time for the follow-up phone call. Thereafter they completed all questionnaires online, collecting COM data and the last page provided a short debrief of the nature of the study and reminded participants about the follow-up. The researcher rang participants to complete the IPAQ via phone 1 week after completing the baseline questionnaires. The day before the follow-up phone call was due, a reminder email was sent. Participants who then answered the call were asked the IPAQ questions about their MVPA for the past seven full days. Participants were then debriefed fully and thanked over the phone.

Analysis

The PLS technique was employed to obtain estimates and fit indices for the proposed measurement and prediction model within the context of SEM using SmartPLS 3 software (Garson, 2016; Hair Jr et al., 2014; Ringle et al., 2015). Prior to running the analysis, boxplots were used to explore the distributions of the measures for anomalies such as outliers and deviation from normality. Total MVPA MET scores showed a positively skewed distribution (skewness = 1.31) and were, therefore, submitted to a square root transformation (skewness = -.06).

The default settings of the PLS algorithm were used to obtain the weights for the outer (i.e. the measurement model) and inner model (i.e. the path model of the constructs) and no convergence problems occurred. Multicollinearity within the inner model was minimal (VIF < 2) and within the outer model acceptable using 5 as the suggested cutoff (Garson, 2016); the highest VIF was 4.7. Confidence intervals for the path coefficients were obtained through a bootstrapping method. A final measurement model was established through model trimming by removing statistically non-significant ($p > .05$) indicators step by step. The standardised root mean square residual (SRMR) was used to assess model fit overall with .08 used as cutoff for acceptability (Hu and Bentler, 1998). Cross-loadings of the indicators were examined to explore their unique relationship with the construct they were supposed to define. Finally, estimates for the direct and indirect path coefficients of the inner model were obtained as well as the explained variance R^2 for the two endogenous variables, Motivation and MVPA. All coefficients are reported as standardized.

Results

This sample was active overall, with 23.7% achieving the national recommendations of at least 150 minutes of moderate activity and 46.2% achieving at least 75 minutes of vigorous activity. When combining moderate and vigorous activity 53.2% achieved at least 150 minutes. The results for the first PLS analysis of the initial model showed a good fit overall (SRMR = .06) and the cross loadings confirmed that each formative indicator had its highest loading on the appropriate composite COM-B construct (Figure 1a). Multicollinearity was not a problem in the inner model (VIF all < 3) and was acceptable in the outer model (both VIF < 4.6).

Insert figure 1a and 1b about here

There were a number of statistically unreliable indicators which were removed one at a time if its weight was small and non-significant ($p > .10$), leaving a fully trimmed outer model with only statistically significant indicators ($p < .05$), aside from social support (family) which was retained at $p = .077$ (see Figure 1b). Each construct had one salient indicator with a substantial weight (> .50); habits on Capability; subjective norms on Opportunity; exercise self-identity on Motivation. The weights of the other indicators were modest to moderate. Exploration of the inner model revealed that the direct path from Opportunity to MVPA was statistically unreliable ($\beta = -.03$, $p = .78$) and was, therefore, removed.

The residuals in the final trimmed model were small (SRMR = .03) and the cross loadings again confirmed that each formative indicator was most strongly associated with its proposed construct suggesting sufficient discriminant validity, although some of the cross-loadings, notably between Capability and Motivation, were substantial (> .50). Multicollinearity was not a problem in the inner model (VIF all < 2.5) and acceptable in the outer model (Capability and Opportunity VIF = 4.17).

There was no indication of an age or gender effect on MVPA ($p > .15$). The model explained 77% of the variance in Motivation and 50% of the variance in MVPA. Capability ($\beta = .81$, 95% confidence intervals (CI), .75 to .87, $p < .001$) and Opportunity ($\beta = .12$, 95% CI, .04 to .21, $p = .001$) were both significant predictors of Motivation, but only Capability ($\beta = .27$, 95% CI, .09 to .50, $p = .008$) and Motivation ($\beta = .46$, 95% CI, .23 to .66, $p < .001$) had a direct effect on MVPA. Consequently, Opportunity only indirectly influenced MVPA via the mediator Motivation and this effect was very small, $IE = .06$, 95% CI, .01 to .11, $p = .032$. By contrast, the indirect effect of Capability on MVPA through the mediator Motivation was substantial, $IE = .37$, 95% CI, .18 to .53, $p < .001$, and even larger than its direct effect

(*DE* = .27). The total effect of Capability on MVPA was *TE* = .64 making it the most important driver for MVPA, followed by Motivation, *TE* = .46, and finally Opportunity.

Discussion

Our study aimed to empirically validate the constructs of the COM-B model in relation to physical activity in a healthy adult sample. Using the TDF as a framework for the selection of suitable measures for each construct, an initial formative measurement model with 18 indicators was specified. The model trimming process lead to a parsimonious model with nine statistically reliable indicators representing the three COM constructs. In this final model, all three constructs were formed of three measures respectively: Capability was defined by self-monitoring, habits, and action planning (all related to Psychological Capability); Opportunity was defined by social support from family, social support from non-family, and subjective norms (all related to Social Opportunity); Motivation was defined by exercise self-identity, self-efficacy, and intentions (all related to Reflective Motivation). Capability (strongly) and Opportunity (weakly) predicted Motivation, and Capability and Motivation explained a large amount of variance in MVPA. Motivation was a strong mediator for Capability on MVPA and a weak mediator for Opportunity. Overall Capability was the most important driver of MVPA, followed by Motivation. This study is the first to examine the three constructs of the COM-B in this way and test their predictive validity in relation to MVPA. The variance explained compares favourably to other psychological models of physical activity such as the TPB (e.g. Hagger et al., 2002; McEachan et al., 2011).

The three indicators for Capability all belong to the behavioural regulation domain of the TDF and so this construct was entirely defined as Psychological Capability. According to Deci and Ryan (1987) people who act in a self-determined manner by autonomously regulating their actions experience better psychological and physical health. Self-monitoring and action planning, both examples of self-determined regulation, are also related to the habit

strength of physical activity (Gardner and Lally, 2013). Indeed, habits turned out to be the most important formative indicator for the construct. Knowledge did not contribute to Capability with only one of three questions answered correctly on average. Previous research shows that despite knowledge often being one of the key targets of behaviour change interventions, it is not always an important influence on behaviour (Cane et al., 2012; Taylor et al., 2013). The results of this study suggest that physical activity undertaken by healthy adults may not be driven by knowledge about the national guidelines. The TDF domain of skills was not specifically measured for this study as there are no skills specific to performing generic physical activity. If future studies look at a particular activity (e.g. tennis) then specific skills acquired through practice would be of more relevance. Physical Capability, measured through physical ability to perform activity, was not found as important since the physical health of the participants was generally very good. This may be of more importance for other, more sedentary populations.

Opportunity was formed by three measures representing the social influences domain of the TDF. The questionnaires that were used to measure social support as well as subjective norms tapped into the views and actions of important others regarding regular physical activity, and both were relevant for the formation of this construct. However, the influence of subjective norms and parental support on physical activity tends to be small and indirect through its impact on motivations such as intention formation as a crucial mediator (Hagger et al., 2002; Li et al., 2014). This was supported by the indirect effect of Opportunity on MVPA via Motivation in this study. None of the three measures that were selected to represent Physical Opportunity remained in the final model. Previous research has suggested that easy access to sporting facilities can enhance the uptake of physical activity (Halonen et al., 2015). For this sample, the local environment (within a 20 minute walk from their homes) was generally reported to be conducive to walking and physical activity, and where available

the condition of sports facilities was generally good. Thus lack of Opportunity was not a barrier of concern. For a different sample (e.g. those living in an area less conducive to physical activity) the importance of the Opportunity construct for Motivation and MVPA might be higher.

The Motivation construct was formed of three measures, all forms of Reflective Motivation. Exercise self-identity was the leading indicator for Motivation, which is consistent with research showing its importance for developing sufficient motivation to exercise (de Bruijn et al., 2012). Exercise self-identity is also related to perceptions of competence (in this case self-efficacy) about performing physical activity (Vlachopoulos et al., 2011), and relevant for forming an intention to be active (Vlachopoulos et al., 2011). Intentions were an important indicator consistent with many psychological theories such as the TPB, placing them as the key determinant and a consistent predictor of physical activity (McEachan et al., 2011). There is however often a gap between intentions to be active and fulfilment of those intentions (Rhodes and de Bruijn, 2013), and the inclusion of components such as self-regulation, identity, habits, and self-efficacy have been highlighted as consistent predictors of post-intentional physical activity (Rhodes and Yao, 2015). Self-efficacy was also found to be an important indicator, supporting previous research which has found it to be an independent predictor of physical activity (Hagger et al., 2002). Techniques that are effective in changing self-efficacy also often mirror those that change physical activity (Williams and French, 2011).

Michie and colleagues proposed the Behaviour Change Wheel as a new framework for designing interventions with Capability, Opportunity, and Motivation as the key drivers of a specific behaviour (Michie et al., 2011). Their conceptualization of these three constructs was deliberately rather broad, which has the advantage that it can be applied to a range of different types of intervention and corresponding policies for their implementation (Michie et

al., 2011). However, because of this breath researchers are required to carefully select the most appropriate indicators for a particular intervention study and justify their selection on theoretical grounds. We used the most comprehensive published mapping of the TDF onto the COM-B (Cane et al., 2012), which includes ability to control habits as an indicator of Capability (something confirmed by the analysis) and thus separates it from habits as an Automatic Motivation, to which Michie et al. (2014) previously referred. When it comes to developing behaviour change interventions, future research should look at whether habit is better placed within Psychological Capability or Automatic Motivation for different behaviours. A construct validation of the COM-B, therefore, becomes a challenging task as the selection of valid formative indicators for each construct must be based on solid explanations and also borne out by empirical evidence.

We, therefore, argued in favour of a formative measurement model which defines a construct as an index through a theoretically well-justified selection of indicators (Bollen and Diamantopoulos, 2015). This flexibility in the operationalization of the COM-B constructs is required as their content varies depending on the availability of appropriate validated measures, and the target behaviour and population in question. Our study showed how the TDF can be utilized as a guiding theoretical framework for the selection and justification of measures to define indices representing the COM-B constructs, and, therefore, also makes a contribution to a recent debate regarding the balance between systematisation and variability in theory application (see Ogden, 2016, and associated commentaries).

With the successful formation of three indices representing Capability, Opportunity, and Motivation, it then became possible to examine their predictive validity and the role of Motivation as a mediator. Michie et al. (2011) did not elaborate on the role of Motivation as a mediator of the influence of Capability and Opportunity on a target behaviour. Rather, the COM-B allows for complex and reciprocal relationships between these drivers and the

behaviour. We specified in our study a unidirectional recursive path model (Kline, 2016). Capability strongly impacted on Motivation and its indirect effect on MVPA via Motivation was even stronger than its direct effect. The very strong direct effect of Capability on Motivation can be understood as reflecting the importance of habits as well as autonomous actions leading to a strengthening of intrinsic motivation in terms of self-efficacy and intentions, and it shows the importance of physical activity as part of one's self-identity, at least in this sample. This then leads to an initiation and maintenance of physical activity as represented by the substantial link between Motivation and MVPA (Deci and Ryan, 1987; Vlachopoulos et al., 2011).

A major strength of this study is the novel approach to the statistical modelling of the COM-B constructs which were defined as latent variables within the context of a formative measurement model using PLS (Henseler et al., 2016). Furthermore, the operationalization of the constructs was based on the TDF and then empirically validated. The time lag between the measurement of the constructs and MVPA is a strength of the paper as it limits demand characteristics. Motivation was an important mediator of the influence of Capability which turned out to be the key driver of MVPA for healthy adults, and so both constructs should be promising targets for an intervention aimed at encouraging or maintaining physical activity. Recent work has begun to show how TDF domains can be linked to individual BCTs (Cane et al., 2015), and identified those BCTs that are included in effective interventions for inactive adults (Howlett et al., 2015).

With respect to limitations, it is important to note that our study used opportunistic sampling to recruit a healthy sample that enjoyed good access to local exercise facilities and had the physical ability to engage in physical activity. Consequently, relevant components in the TDF reflecting differences in physical capabilities and opportunities did not contribute to the formation of the COM-B constructs in this sample. For populations that are less active,

suffering from chronic health problems, or living in environments offering limited facilities, Physical Capability and Opportunity are likely to be more important. Furthermore, two TDF domains (memory, attention, and decision making; reinforcement) were not included in the initial measurement model because of a lack of validated measures. Our strategy for empirically validating the COM-B using a formative measurement model relied on a data-driven approach and so a cross-validation with an independent similar sample would be desirable to strengthen the generalizability of the conclusions. Finally, our approach measured behaviour over just one week, and so we cannot comment on the temporal stability of the model.

Conclusions

The COM-B constructs of Psychological Capability and Reflective Motivation were predictive of physical activity in a healthy adult population. The inclusion of components from a range of TDF domains in a formative measurement model elucidates how the COM-B can be operationalised. Research going forward should consider using this systematic mapping of TDF domains to conceptualise the COM-B for distinct behaviours and populations. This study provides evidence that the COM-B is a useful model for predicting physical activity and has identified a number of TDF domains that should represent key targets to address through relevant BCTs in order to change MVPA in future interventions.

References

Ajzen I (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes 50*(2): 179-211.

Alexander KE, Brijnath B and Mazza D (2014). Barriers and enablers to delivery of the Healthy Kids Check: an analysis informed by the Theoretical Domains Framework and COM-B model. *Implementation Science* 9: 60.

Anderson DF and Cychosz CM (1994). Development of an exercise identity scale. *Perceptual and Motor Skills* 78(3): 747-751.

Bollen K and Lennox R (1991). Conventional wisdom on measurement: a structural equation perspective. *Psychological Bulletin* 110(2): 305-314.

Bollen KA and Diamantopoulos A (2015). In defense of causal–formative indicators: minority report. doi.org/10.1037/met0000056

Bridle C, Riemsma RP, Pattenden J, et al. (2005). Systematic review of the effectiveness of health behavior interventions based on the transtheoretical model. *Psychology & Health* 20(3): 283-301.

Cane J, O'Connor D and Michie S (2012). Validation of the theoretical domains framework for use in behaviour change and implementation research. *Implementation Science* 7(1): 37.

Cane J, Richardson M, Johnston M, et al. (2015). From lists of behaviour change techniques (BCTs) to structured hierarchies: comparison of two methods of developing a hierarchy of BCTs. *British Journal of Health Psychology* 20(1): 130-150.

Craig CL, Marshall AL, Sjostrom M, et al. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine and Science in Sports and Exercise* 35(8): 1381-1395.

de Bruijn G, Verkooijen K, de Vries NK, et al. (2012). Antecedents of self identity and consequences for action control: An application of the theory of planned behaviour in the exercise domain. *Psychology of Sport and Exercise* 13: 771-778.

Deci EL and Ryan RM (1987). The support of autonomy and the control of behaviour. *Journal of Personality and Social Psychology* 53(6): 1024-1037.

Diamantopoulos A and Winklhofer HM (2001). Index construction with formative indicators: An alternative to scale development. *Journal of Marketing Research* 38(2): 269-77.

Echeverria MSE, Diez-Roux AV and Link BG (2004). Reliability of self-reported neighborhood characteristics. *Journal of Urban Health* 81(4): 682-701.

Francis JJ, Eccles MP, Johnston M, et al. (2004). Constructing questionnaires based on the theory of planned behaviour. *A manual for health services researchers* 2-12.

Gardner B and Lally P (2013). Does intrinsic motivation strengthen physical activity habit? Modeling relationships between self-determination, past behaviour, and habit strength. *Journal of Behavioural Medicine* 36(5): 488-197.

Garson DG (2016). Partial least squares: Regression and structural equation models. Retrieved from http://info.smartpls.com/data/uploads/ebook_on_pls-sem.pdf

Hagger MS, Chatzisarantis NL and Biddle SJ (2002). A meta-analytic review of the theories of reasoned action and planned behavior in physical activity: Predictive validity and the contribution of additional variables. *Journal of Sport and Exercise Psychology* 24: 3-32.

Hair Jr JF, Hult G, Tomas M, et al. (2014). *A primer on partial least squares structural equation modeling (PLS-SEM)*. Thousand Oaks, CA: Sage Publications.

Halonen JI, Stenholm S, Kivimäki M., et al. (2015). Is change in availability of sports facilities associated with change in physical activity? A prospective cohort study. *Preventive Medicine* 73: 10-14.

Henseler J, Hubona G and Ray PA (2016). Using PLS path modeling in new technology research: updated guidelines. *Industrial Management and Data Systems* 116(1): 2-20.

Hoffmann TC, Glasziou PP, Boutron I, et al. (2014). Better reporting of interventions: template for intervention description and replication (TIDieR) checklist and guide. *BMJ* 348: g1687.

Howlett N, Trivedi D, Troop NA, et al. (2015). What are the most effective behaviour change techniques to promote physical activity and/or reduce sedentary behaviour in inactive adults? A systematic review protocol. *BMJ Open* 5: e008573.

Hu L, and Bentler PM (1998). Fit indices in covariance structure modeling: Sensitivity to underparameterized model misspecification. *Psychological Methods* 3(4): 424-453.

International Physical Activity Questionnaire. (2005). Guidelines for data processing and analysis of the international physical activity questionnaire (IPAQ). International Physical Activity Questionnaire website. Retrieved August, 16, 2014 from https://sites.google.com/site/theipaq/scoring-protocol.

Kline RB (2016). *Principles and practice of structural equation modelling. 4th edition*. Guilford Publications.

Lee PH, Macfarlane DJ, Lam T, et al. (2011). Validity of the international physical activity questionnaire short form (IPAQ-SF): A systematic review. *International Journal of Behavioral Nutrition and Physical Activity* 8(1): 115.

Li K, Iannotti RJ, Haynie DL, et al. (2014). Motivation and planning as mediators of the relation between social support and physical activity among U.S. adolescents: a nationally representative study. *International Journal of Behavioral Nutrition and Physical Activity* 11(1): 42.

McEachan RRC, Conner M, Taylor NJ, et al. (2011). Prospective prediction of health-related behaviours with the Theory of Planned Behaviour: ameta-analysis. *Health Psychology Review* 5(2): 97-144.

Michie S, Atkins L, and West R (2014). *The Behaviour Change Wheel: A Guide To Designing Interventions*. Sutton: Silverback Publishing.

Michie S, Fixsen D, Grimshaw JM, et al. (2009). Specifying and reporting complex behaviour change interventions: the need for a scientific method. *Implementation Science* 4(40): 1-6.

Michie S, Johnston M, Abraham C, et al. (2005). Making psychological theory useful for implementing evidence based practice: a consensus approach. *Quality and Safety in Health Care* 14(1): 26-33.

Michie S, Richardson M, Johnston M, et al. (2013). The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. *Annals of Behavioral Medicine* 46(1): 81-95.

Michie S, van Stralen MM and West R (2011). The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implementation Science* 6(1): 42.

Ogden J (2016). Celebrating variability and a call to limit systematisation: the example of the Behaviour Change Technique Taxonomy and the Behaviour Change Wheel. *Health Psychology Review* 10(3): 245-250.

Perron BE and Gillespie DF (2015). *Key Concepts in Measurement*. Oxford University Press.

Prestwich A, Sniehotta FF, Whittington C, et al. (2014). Does theory influence the effectiveness of health behavior interventions? Meta-analysis. *Health Psychology* 33(5): 465.

Prochaska JO and DiClemente CC (1982). Transtheoretical therapy: Toward a more integrative model of change. *Psychotherapy: Theory, Research & Practice* 19(3): 276.

Rhodes RE and Bruijn GJ (2013). How big is the physical activity intention–behaviour gap? A meta-analysis using the action control framework. *British Journal of Health Psychology* 18(2): 296-309.

Rhodes RE and Dickau L (2012). Experimental evidence of the intention-behaviour relationship in the physical activity domain: A meta-analysis. *Health Psychology* 31(6): 724-727.

Rhodes RE, Janssen I, Bredin SS, et al. (2017). Physical activity: Health impact, prevalence, correlates and interventions. *Psychology & Health* 32(8): 942-975.

Rhodes RE and Yao CA (2015). Models accounting for intention-behavior discordance in the physical activity domain: a user's guide, content overview, and review of current evidence. *International Journal of Behavioral Nutrition and Physical Activity* 12(1): 9.

Ringle CM, Wende S and Becker JM (2015). *SmartPLS 3*. Boenningstedt: SmartPLS GmbH. Retrieved from http://www.smartpls.com.

Rzewnicki R, Auweele YV and Bourdeaudhuij ID (2003). Addressing overreporting on the International Physical Activity Questionnaire (IPAQ) telephone survey with a population sample. *Public Health Nutrition* 6(3): 299-305.

Sallis JF, Grossman RM, Pinski RB, et al. (1987). The development of scales to measure social support for diet and exercise behaviors. *Preventive Medicine* 16(6): 825-836.

Schwarzer R and Renner B (2009). Health-specific self-efficacy scales. *Freie Universität Berlin.* Retrieved March 14, 2015.

Sniehotta FF, Scholz U, Schwarzer R, et al. (2005). Long-term effects of two psychological interventions on physical exercise and self-regulation following coronary rehabilitation. *International Journal of Behavioral Medicine* 12(4): 244-255.

Sniehotta FF, Schwarzer R, Scholz U, et al. (2005). Action planning and coping planning for long-term lifestyle change: theory and assessment. *European Journal of Social Psychology* 35(4): 565-576.

Sporting future – First annual report. 2017 https://www.gov.uk/government/publications/sporting-future-first-annual-report Accessed March 9 2017.

Taylor N, Lawton R and Conner M. (2013). Development and initial validation of the determinants of physical activity questionnaire. *International Journal of Behavioral Nutrition and Physical Activity* 10(1): 74.

Thompson ER (2007). Development and validation of an internationally reliable short-form of the positive and negative affect schedule (PANAS). *Journal of Cross-cultural Psychology* 38(2): 227-242.

Verplanken B and Orbell S (2003). Reflections on past behavior: a self-report index of habit strength. *Journal of Applied Social Psychology* 33(6): 1313-1330.

Vlachopoulos SP, Kaperoni M and Moustaka FC (2011). The relationship of self-determination theory variables to exercise identity. *Psychology of Sport and Exercise* 12: 265-272.

Ware Jr JE and Sherbourne CD (1992). The MOS 36-item short-form health survey (SF-36): I. Conceptual framework and item selection. *Medical Care* 473-483.

Webb TL and Sheeran P (2006). Does changing behavioral intentions engender behaviour change? A meta-analysis of the experimental evidence. *Psychological Bulletin* 132(2): 249.

Williams S and French D (2011). What are the most effective intervention techniques for changing physical activity self-efficacy and physical activity behaviour—and are they the same? *Health Education Research* 26(2): 308-322.

Table 1: Mapping of COM-B to the TDF domains, with the appropriate questionnaire measures representing key indicators (based on Cane et al., 2012).

COM-B component	TDF Domain	Indicator and measure
Capability	Knowledge	Knowledge (Physical activity guideline questions; NHS Choices)
	Memory, attention and decision making	*No appropriate validated measures*
	Behavioural regulation	Self-monitoring (Sniehotta et al., 2005a) Breaking habit (Self-report habit index; Verplanken and Orbell, 2003) Action planning (Sniehotta et al., 2005b)
	Physical ability (Skills)	Ability (Medical Outcomes Short Form Survey; Ware and Sherbourne, 1992)
Opportunity	Social influences	Social support (family and non-family) (Social Support for Exercise Behaviour Scale; Sallis et al., 1987) Social/group norms (subjective norms; Francis et al., 2004)
	Environmental context and resources	Barriers and facilitators (Neighbourhood Environment Scale; Echeverria et al., 2004) Resources/material resources (Presence of Recreational Facilities Index; Echeverria et al., 2004)

Motivation	Social/professional role and identity, Optimism	Identity (Exercise Self-Identity Scale; Anderson and Cychosz, 1994))
	Beliefs about capabilities	Self-efficacy (Physical Exercise Self-Efficacy Scale; Schwarzer and Renner, 2009) Perceived behavioural control (Francis et al., 2004)
	Beliefs about consequences	Beliefs (Attitudes; Francis et al., 2004)
	Intentions	Intentions (Francis et al., 2004)
	Goals	Covered by action planning (included in capability)
	Reinforcement	*No appropriate validated measures*
	Emotion	Positive/ negative affect (International Positive and Negative Affect Schedule Short Form; Thompson, 2007)

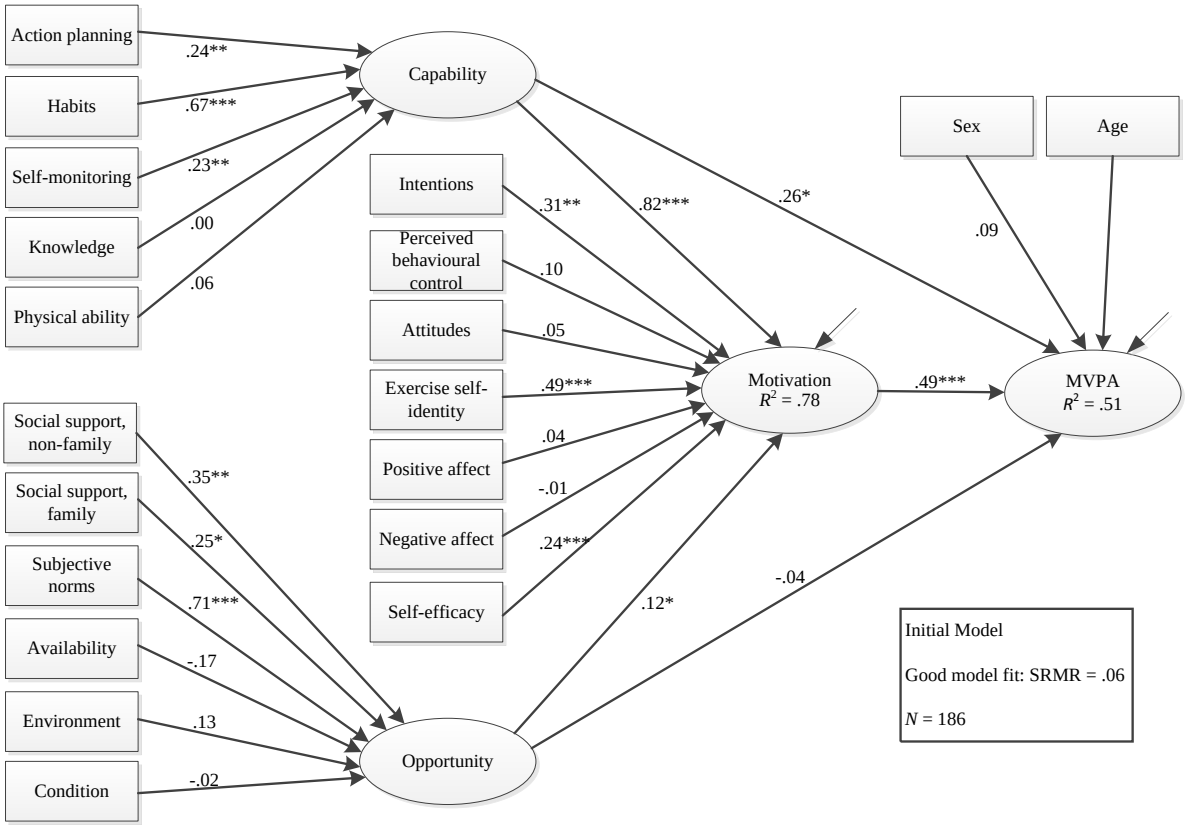

Figure 1a

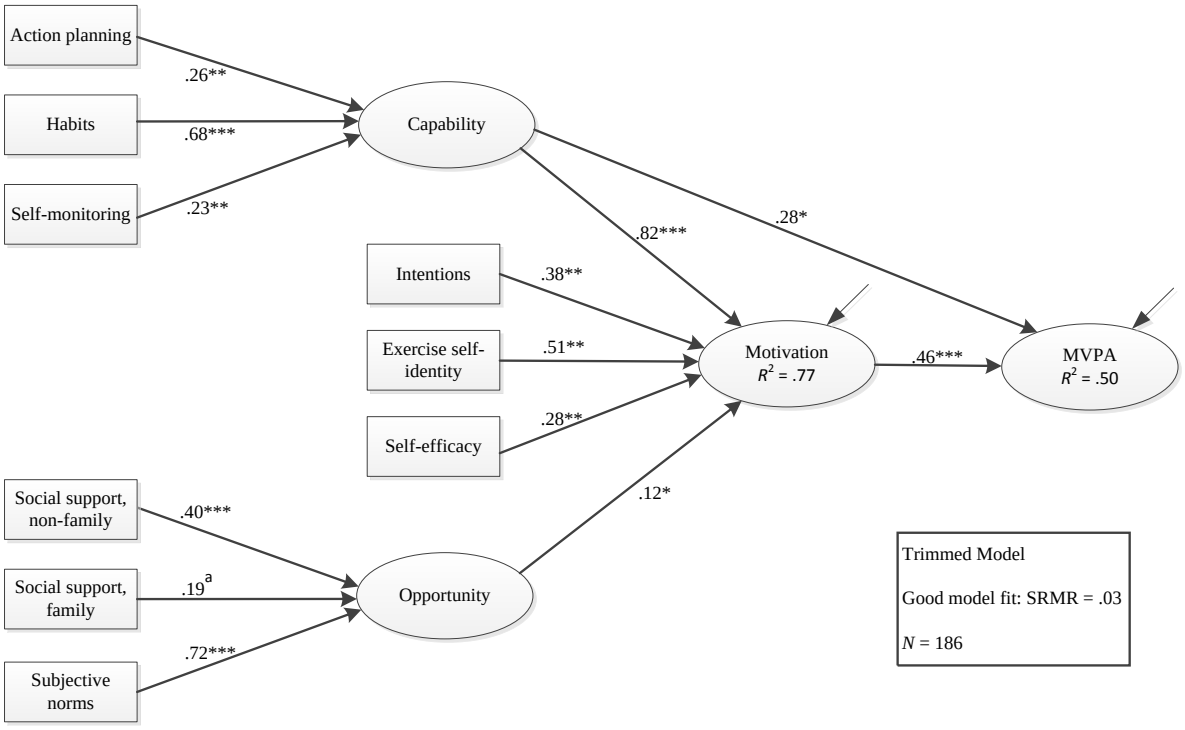

Figure 1b

Figure 1a – Specified formative measurement model of the COM-B. Constructs are represented by ovals and observed variables by rectangles. Outer weights of indicators and path coefficients are standardized.
Figure 1b – Trimmed model after removing indicators with non-significant outer weights

Note: *$p < .05$, **$p < .01$, ***$p < .001$, $^{a}p < .10$

Supplementary Table 1. Sample demographics and descriptive statistics for the dependent variables and all formative indicators (N = 186).

Characteristics		Means (SD)[a] and frequencies (percentages)[b]	Formative indicators (range) and dependent variables	Mean (SD)
Age[a]		38.25 (14.12), range 18-74	Knowledge (0-3)	1.10 (.96)
			Physical Health (1-3)	2.87 (.26)
BMI[a]		24.58 (4.67), range 14.3-44.1	Self-Efficacy (5-20)	14.26 (3.86)
			Attitudes (1-7)	6.31 (.76)
Female[b]		132 (71%)	Intentions (1-7)	6.10 (1.49)
			Subjective Norms (1-7)	5.03 (1.62)
Smoker[b]		10 (5%)	Perceived Behavioural Control (1-7)	5.71 (1.27)
			Habits (1-7)	4.42 (1.76)
Highest	Up to A Level	43 (23%)	Local Environment (10-50)	37.68 (6.50)
education level	Bachelors degree	60 (32%)	Availability (1-6)	3.47 (1.36)
(or equivalent)[b]:	Masters degree	62 (33%)	Condition (1-4)	3.02 (.65)
	PhD	22 (12%)	Self-Monitoring (1-4)	2.46 (.96)

Employment[b]:	Full-time work	88 (47%)
	Part-time work	30 (16%)
	Full-time student	37 (20%)
	Other	32 (17%)
Household	£0-25000	22 (12%)
Salary[b]:	£25-50000	63 (34%)
	£50-75000	34 (18%)
	Over £75000	32 (17%)
Marital Status[b]:	Married	81 (43%)
	Living with partner	32 (17%)
	Single	53 (28%)
	Other	21 (11%)

Action Planning (1-4)	2.47 (1.03)
Social Support (Non-family) (5-25)	9.05 (5.18)
Social Support (Household) (5-25)	8.44 (4.58)
Positive Affect (5-25)	17.71 (3.53)
Negative Affect (5-25)	10.37 (3.41)
Exercise Self-Identity (1-7)	4.78 (1.88)
Vigorous Minutes per week	95.49 (121.12)
Vigorous Activity METS per week	763.94 (968.98)
Moderate Minutes per week	109.79 (170.71)
Moderate Activity METS per week	439.15 (682.84)
Total METS per week	1203.09 (1147.07)